

## AS Unit 1: Basic Biochemistry and Cell Organisation

Name:	Date:
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### **Topic 1.6 Cell Division** – Page 2

#### I. **Mitosis**

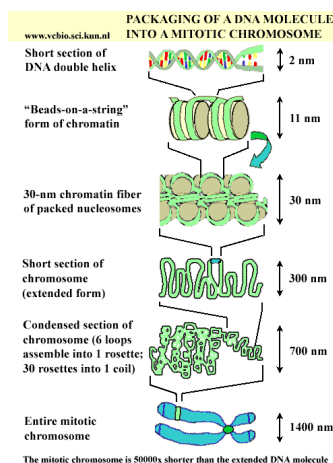
		Completed
1.	Go through the Cell Division PPT	
2.	Read the Following: <ul style="list-style-type: none"><li>• Rowlands p61-64</li><li>• Toole p</li></ul>	
3.	Read pages 2-6	
4.	Complete the activities on p7-11	
5.	Complete the Mitosis Quiz on p12	
	Go through the BSR Revision PPT on Cell Division Complete BSR Cell Cycle Questions p13-15	

## CHROMOSOME STRUCTURE

1. During nuclear division, the DNA (as **chromatin**) in a Eukaryotic cell's nucleus is coiled into very tight compact structures called **chromosomes**. These are rod-shaped structures made of protein and DNA, **which are visible (when stained) only during nuclear division**.
2. The DNA in Eukaryotic cells is coiled tightly around proteins called **histones**, which help in the tight packing of DNA. During interphase, the DNA is not tightly coiled into chromosomes, but exists as **chromatin**.
3. When preparing for nuclear division, during the S phase of interphase, the chromosomes copy themselves (i.e. DNA replication occurs). Each half of the chromosome is now called a **chromatid**. **Note that there is still only one chromosome**; it consists of **two chromatids** but has only **one centromere**. The function of this is to hold the two chromatids together until they separate during anaphase.
4. Chromosomes are simpler in Prokaryotes. Their DNA is in a single chromosome, and exists as a loop (ccc DNA).

## CHROMOSOME NUMBERS

1. Each human **somatic** (or body) cell contains two complete sets of chromosomes (one from each parent). This is the normal for Eukaryotes and is known as **diploid (2n)**. For humans (only) this means our cells have 46 chromosomes. **For other species, this number can be very different** – e.g. Lettuce 14, Goldfish 94. Such cells are formed by **mitosis**.
2. Sex cells (**gametes** – **eggs** and **sperm**) have only one set of chromosomes (in humans, 23) and such cells are known as **haploid (n)**. **Each cell is unique**, as it is produced by **meiosis** (though the ‘mother cells’ for the gametes are produced by mitosis, the final division is always meiotic).
3. Meiosis is necessary because most organisms reproduce sexually, and during **fertilisation**, the gametes fuse and the number of chromosomes therefore doubles (sperm (n) + egg (n) = 2n), to produce the first cell of the next generation – the **zygote (2n)**.
4. Chromosomes can be divided into two types. In humans, we have 22 pairs of **autosomes**, which are the same in every individual, and one pair of **sex chromosomes** (XX = female, XY = male). This means that females are the **homozygous sex** and males the **heterozygous sex**. The effect of this is that **females can be carriers for sex-linked characteristics** (e.g. colour-blindness), but it is (almost) always males that are afflicted (Exception: if a **female carrier marries an afflicted male; half their female children will be afflicted**.) Note that, in birds, the opposite applies; males are XX (carriers) and females are XO (and thus have the condition).
5. The two matching sets of autosomes are known as **homologous pairs**, and both will code for the same features (have the same **genes**, e.g. for eye colour), but they may well have different **alleles** (e.g. blue or brown).



## CELL DIVISION

### PROKARYOTES

1. Prokaryotic cells divide by **binary fission**, in which the DNA replicates and then the cell divides in two. That's all – no mitosis, no spindle, no nothing!

### EUKARYOTES

1. A cell typically goes through three phases during its life, beginning with growth before it can divide. This is known as the **cell cycle** and consists of three phases:

A. **Interphase** B. **Mitosis** (nuclear division, producing **2 identical nuclei**) C. **Cytokinesis** (cell division, producing **2 roughly equal cells**)

# THE CELL CYCLE

## A. INTERPHASE

1. This is the longest phase of the cell cycle and can last from a few hours to many years. It used to be known as the 'resting phase', which is completely misleading, as it is during this time of normal metabolic activity that the cell performs all its normal functions, beginning with growth and development.

2. Interphase can be divided into 3 stages:

I. **G1 Phase** - A period of normal metabolic activity – the number of cell organelles increases to normal levels and the volume of cytoplasm increases too, eventually reaching mature size. A cell can remain in this phase indefinitely.

II. **S Phase** - The DNA and chromosomes replicate. The cell is now committed to division.

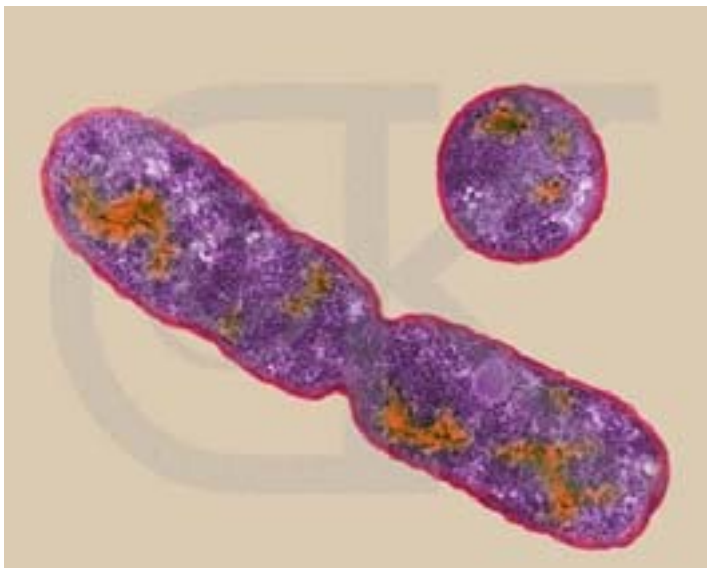
III. **G2 Phase** - Structures directly involved with mitosis are formed. The new DNA is checked for errors and the substances that will be needed during mitosis are synthesised.

B. MITOSIS 1. Mitosis is only the division of the nucleus into two identical nuclei. It is a continuous process,

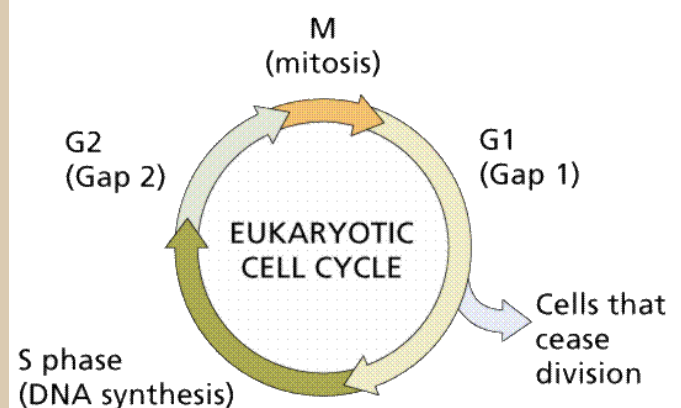
but has been artificially divided into 4 steps. These can be remembered as **I Pee MAT**:

I. Prophase II. Metaphase

III. Anaphase IV. Telophase



I. Prophase



1. The chromatin condenses into chromosomes by dehydrating and coiling. The chromosomes consist of two identical sister chromatids, joined together by a centromere. For the first time, they can be seen with a light microscope.

2. The nucleolus and nuclear envelope disappear, and the centriole (animal cells only) divides into two centrosomes, which move apart, creating the spindle. This eventually fills the whole of the cell and is made of the protein tubulin which forms spindle fibres – a form of microtubule.

II. Metaphase

The chromosomes are moved to the equator of the cell, and the centromeres are attached to the spindle fibres, so that the sister chromatids line up in the centre of the cell.

III. Anaphase

The centromeres of each chromosome divide and are pulled apart by the contraction of the spindle fibres, thus moving the **chromosomes** (as they must now be called) to opposite poles of the cell.

#### IV. Telophase

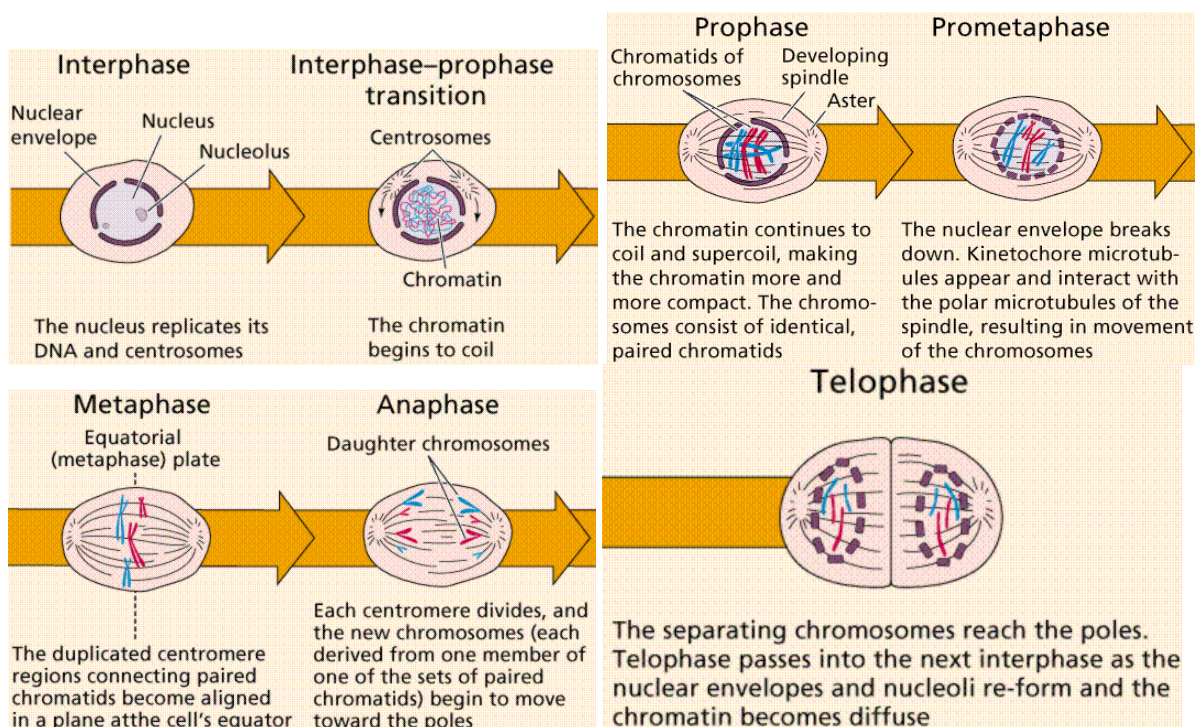
1. After the chromosomes reach the poles, the spindle disappears and the chromosomes return to their functional chromatin state by rehydrating and uncoiling.
2. A new **nuclear envelope** begins to form around the chromosomes at each end of the cell, each with its own nucleolus. With mitosis now over, **cytokinesis** can begin.

#### C. CYTOKINESIS

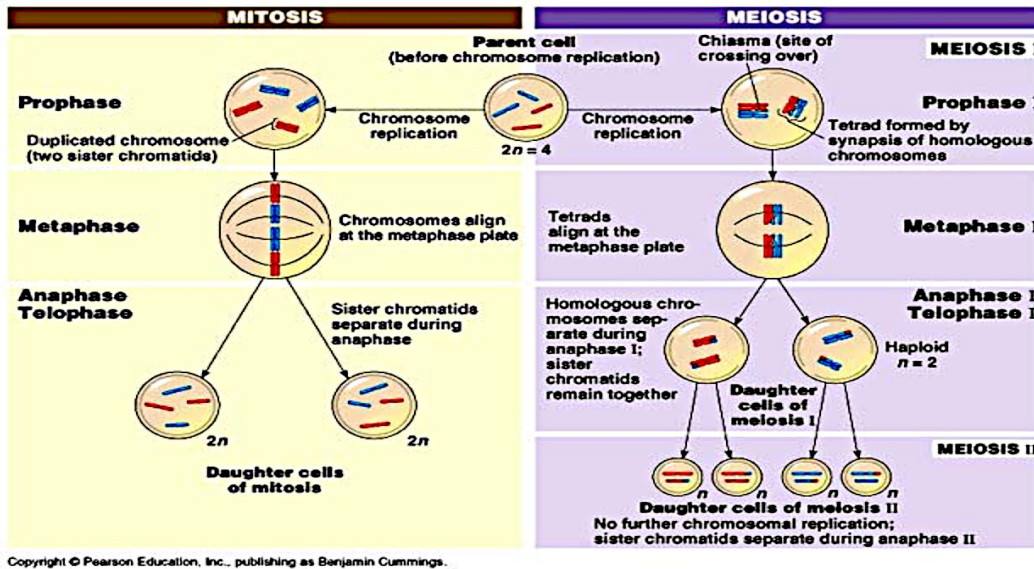
1. Following mitosis, cytokinesis completes the process of cell division. The two cells formed are roughly equal in size. It is rather different in animal and plant cells:

I. Animal cells. The cytoplasm divides by the pinching of the cell in the middle. II. Plant cells. In a plant cell, a new cell wall begins to form across the centre of the cell, along the line of the cell plate (or middle lamella), which is made of pectin. A new cellulose cell wall is then laid down on both side of this, and new cell membranes form inside that, leaving gaps through which the cytoplasm of one cell links to that of its sister. These gaps

are known as plasmodesma (pl. plasmodesmata).



#### MEIOSIS



Meiosis is a nuclear division that reduces the number of chromosomes in new cells to half the original number (diploid,  $2N \rightarrow$  haploid,  $N$ ). This counteracts the fusion of cells in fertilisation (haploid,  $N \rightarrow$  diploid,  $2N$ ). Crucially, it also **produces unique gametes**, which means that **sexual reproduction results in variation**, the raw material for evolution. Whilst mitosis can occur anywhere in an animal, meiosis is confined to the **gonads** (sex organs).

1. Most organisms reproduce sexually, by the fusion of separate male (= **sperm**) and female (= **egg** or **ovum**) gametes. Eggs are much larger and non-motile; sperm are the smallest human cell and swim by means of a flagellum. Reproduction therefore depends on water.

2. Meiosis is the second type of nuclear division, but in this case the number of chromosomes is halved. As in mitosis, meiosis is followed by cytokinesis. It is otherwise very different:

I. Meiosis produces daughter cells with half the number of chromosomes of the parent cell, i.e. the cell goes from diploid to haploid.

II. **Meiosis consists of two nuclear divisions**, resulting in **four haploid daughter cells**.

III. The cells produced by meiosis are not all alike. Each cell is unique and this variation is produced by two processes – **independent segregation** of the chromosomes and by **crossing-over**. Both take place during Meiosis I.

## STAGES OF MEIOSIS

Meiosis consists of two divisions:

A. During **meiosis I** homologous pairs of chromosomes are separated **and cells become haploid**.

B. During **meiosis II** the sister chromatids of each chromosome are separated (as in mitosis).

### Meiosis I

1. At the start of meiosis, each chromosome consists of **two sister chromatids**, connected at the centromere. However, meiosis differs from mitosis, in that homologous pairs of chromosomes come together at the start of the meiosis, in a process called **synapsis**, forming a **tetrad**.

### Prophase I.



1. Just as in mitosis, the nucleolus and nuclear membrane disappear, and the centriole divides and forms the spindle. As in mitosis, the chromosomes dehydrate and become thick and visible, but with the chromosomes of each homologous pair tangled together. There are thus **four chromatids in each pair of chromosomes** (N.B. and so only half as many 'sets' visible in diagrams).

2. Portions of each chromatid may break off and reattach to an adjacent chromatid on the homologous chromosome. The places where this happens are called **chiasma** (pl. **chiasmata**). The whole process is called **crossing-over** and it results in unique combination of alleles on each chromatid. **Crossing-over can only take place between genes**. This is an essential part of the **genetic recombination** that takes place in meiosis.

**Metaphase I.** Homologous pairs are still together and arranged on the equator of the cell.

**Anaphase I.** The homologous pairs of chromosomes separate from each other, as the spindle fibres pull one of each pair to opposite ends of the cell. The random separation of the homologous chromosomes that this produces is called **independent assortment**, and results in  $2^{23}$  different gametes being possible from any one human being – a couple could have  $2^{46}$  different children!

**Telophase I.** Cytokinesis takes place; and **each new cell is haploid**, containing one chromosome from each pair.

## MEIOSIS II

1. In males, this follows immediately. In females, meiosis I takes place before birth, but meiosis II takes place only after the sperm has fused with the egg (i.e. immediately before fertilisation). The chromosomes do not replicate before this, second, division, **so the gametes formed will have only half the DNA of a normal cell**.

2. The **second division of meiosis is essentially the same as mitosis**. Often Telophase I is omitted and, after cell division, both daughter cells are already at the end of prophase II.

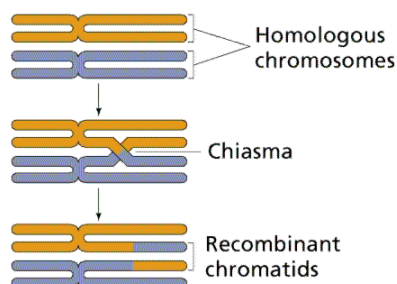
**N.B.** When answering questions about the stage of meiosis (in a diagram)

or when a particular event occurs (in words), you **MUST** state if it is the

first or second division. So 'Prophase I' is usually the correct answer,

but 'Prophase' is **ALWAYS WRONG!** Suggestion: when in doubt, the answer is **NORMALLY** Prophase I, but **ALWAYS** in division I, as division II looks the same as mitosis.

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The table below shows the lengths of the periods of the cell cycle, in hours, for human cells in tissue culture, the root tips of broad beans and of the plant *Tradescantia paludosa*.

Material	Time spent in each phase (hours)				
	Interphase	G1	S	G2	M
Human cells in culture at 36°C	24.3	13.0	7.4	3.9	1.5
Broad beans at 20°C	14.4	2.4	4.0	8.0	3.6
<i>Tradescantia</i> at 20°C	19.1	5.8	10.8	2.5	1.7
<i>Tradescantia</i> at 30°C	14.3	2.4	9.5	2.4	1.7

- How long is the cell cycle of human cells in culture?  


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- Calculate the percentage of interphase occupied by DNA replication in Broad Beans.  


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- How many minutes do mitosis and cytokinesis take in *Tradescantia* at 20°C?  


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- Which phase of the cell cycle is most affected by temperature in *Tradescantia*? Make suitable calculations from the table to support your answer.  


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Go to the following website and complete the table below:

[http://www.biology.arizona.edu/cell\\_bio/activities/cell\\_cycle/cell\\_cycle.html](http://www.biology.arizona.edu/cell_bio/activities/cell_cycle/cell_cycle.html)

	Interphase	Prophase	Metaphase	Anaphase	Telophase	Total
Number Of cells						36
Percentage of cells						100

1. At what stage does the nuclear membrane disappear?

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2. At what stage does the nucleolus disappear?

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3. What is the function of the nucleolus?

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4. When does the nuclear membrane reappear?

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5. When does the nucleolus reappear?

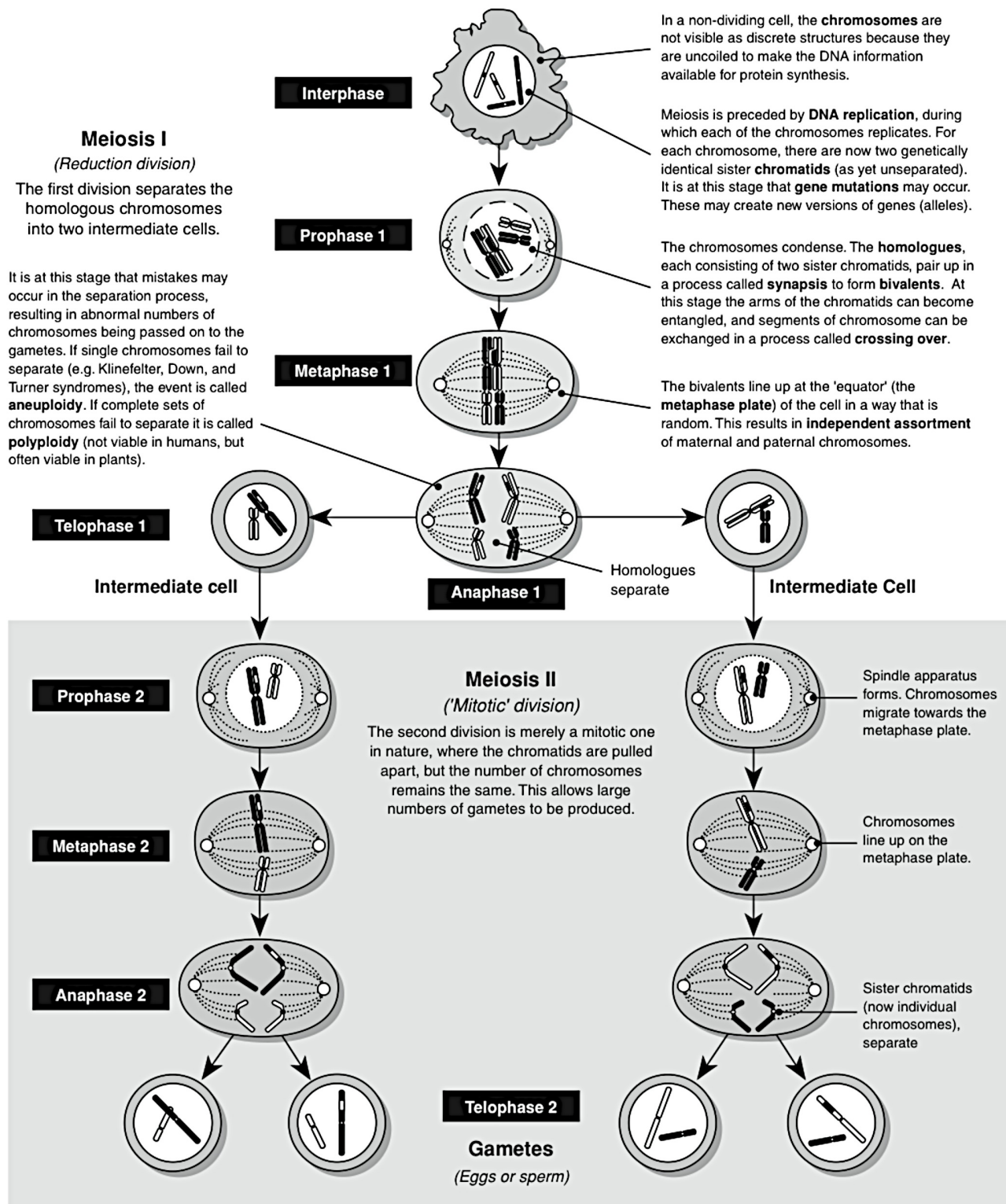
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# Meiosis

The process of **meiosis** is a special type of cell division concerned with producing sex cells (gametes) for the purpose of sexual reproduction. This cell division occurs in the sex

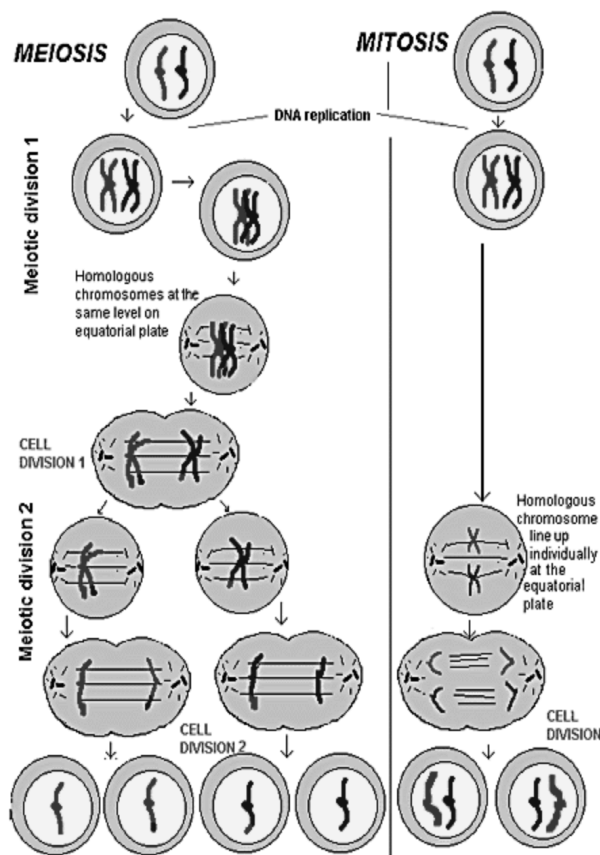
organs of plants and animals. If genetic mistakes (**gene** and **chromosome mutations**) occur here, they will be passed on to the offspring (they will be inherited).



1. Describe the behaviour of the chromosomes in the first division of meiosis: \_\_\_\_\_

2. Describe the behaviour of the chromosomes in the second division of meiosis: \_\_\_\_\_

## Comparison of Meiosis and Mitosis



### Significance of meiosis and mitosis

In mitosis the significance is the ability to produce genetically identical daughter cells. These will be needed for **growth**, for the **replacement** of damaged and destroyed cells and for **asexual reproduction**.

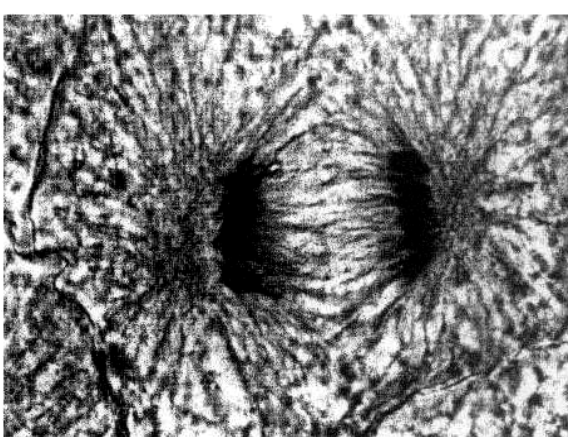
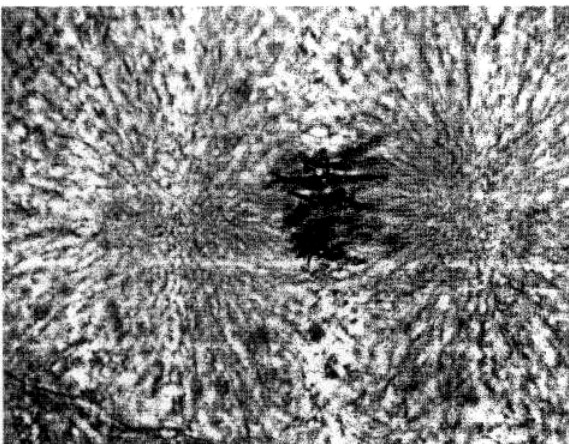
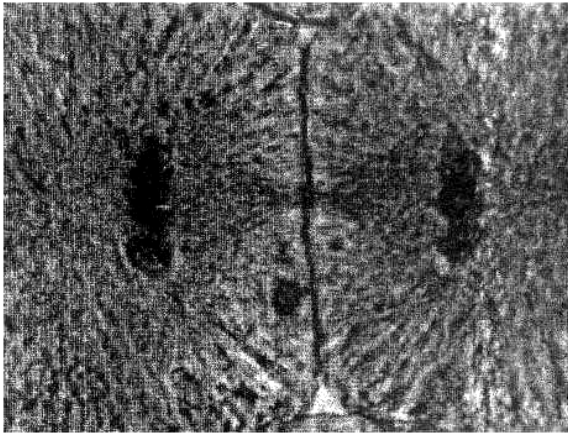
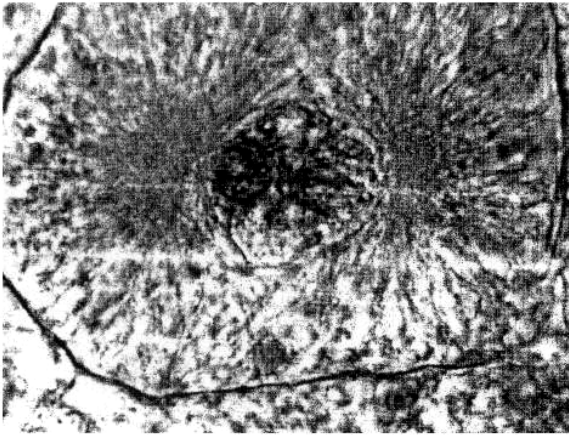
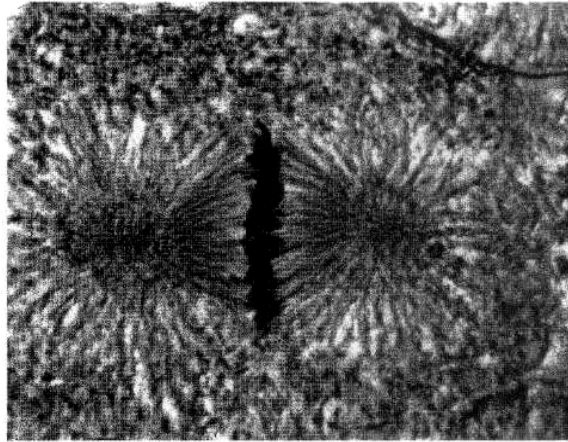
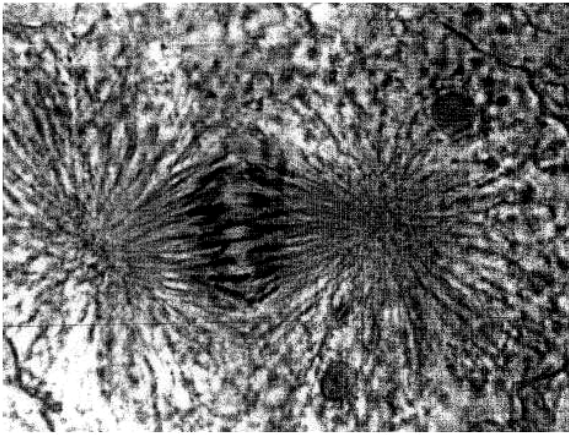
The significance of meiosis lies in sexual reproduction and to produce **variation in the offspring**. This variation is the key to a species ability to adapt to change in the environment and survive.

Producing haploid gametes so that the genotypes of parents can be combined brings about **variation**. Homologous chromosomes line up **independently** on the equator therefore generating  $2^n$  different combinations of chromosomes in the gametes. Also crossing over takes place in Prophase I where new combinations of genes can be produced.

### Comparison of Mitosis and Meiosis

Feature	Meiosis	Mitosis
Number of nuclear divisions		
What do homologous chromosomes do in prophase?		
What do homologous chromosomes do in metaphase?		
What happens at anaphase I compared to anaphase in mitosis?		
What happens in anaphase II compared to anaphase in mitosis?		
Number of nuclei produced?		
Haploid or Diploid nuclei produced?		
Are daughter nuclei genetically identical or different to the parent nucleus?		

Below are some light micrographs of cells undergoing mitosis. They are not in any order. Cut them out. Place them in the correct order, stick them onto a sheet of paper and label the stage of mitosis that is being shown.



## Mitosis Quiz

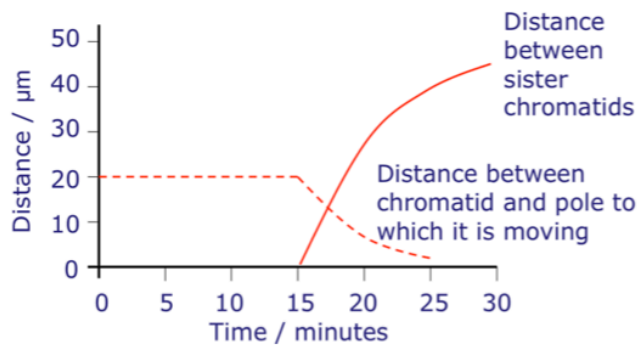
- A.** Stage in mitosis in which chromatids are being pulled apart. (8)
- B.** Viruses which infect bacteria. (14)
- C.** Holds together the two chromatids. (10)
- C.** The name of the two strands making up a chromosome when it appears at prophase. (10)
- C.** The artificial process which produces genetically identical organisms. (7)
- C.** Describes the separation of the cytoplasm in cell division. (11)
- D.** A cell containing two copies of each chromosome. (7)
- E.** Centre of the cell where the chromosomes align. (7)
- F.** The fusion of the male and female gametes. (13)
- H.** A cell containing one copy of each chromosome. (7)
- I.** Name of the stage between the last and next division of the cell. (10)
- M.** Stage in mitosis when chromosomes line up along the equator. (9)
- M.** Type of cell division which produces cells with half the number of chromosomes as the parent cell. (7)
- P.** Opposite ends of the cell. (5)
- P.** First stage of mitosis. (8)
- S.** Name given to the two chromatids which belong to the same chromosome. (6)
- S.** Name of the human male gamete. (5)
- S.** Phase in the cell cycle in which DNA is replicated. (1) (5)
- S.** Protein fibres radiating out from the poles during cell division. (7)
- T.** Last phase of mitosis. (9)
- Z.** Produced by the fusion of two gametes. (6)

## Activity

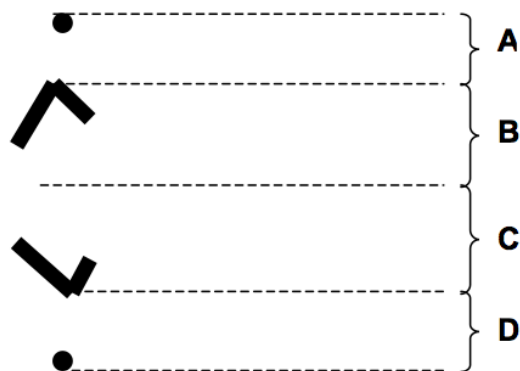
# The cell cycle

## Bill Inge

The graph shows some measurements that were made in a cell that was undergoing mitosis.



1 The diagram shows a pair of chromosomes moving apart during mitosis.



(a) Use one or more of the letters **A** to **D** on the diagram to give:

- (i) the distance between a chromatid and the pole to which it is moving
- (ii) the distance between sister chromatids. (2 marks)

2 Look at the graph. What stage of mitosis was the cell at after 20 minutes? Explain the evidence for your answer. (3 marks)

3 Use the graph to calculate the rate of movement of a chromatid towards a pole of the cell between 15 and 20 minutes. Give your answer in  $\mu\text{m minute}^{-1}$  and show your working. (2 marks)



A scientist made a stained slide of some cells from a plant root tip. She examined the slide under a microscope and counted the number of cells at each phase in the cell cycle. The table shows the data she collected.

Phase of cell cycle	Percentage of cells in this phase
Prophase	9.3
Metaphase	38.8
Anaphase	11.6
Telophase	7.8
Interphase	32.5

**4** Under the conditions in which the plant was growing, the cell cycle in the root tip cells took 20 hours. Calculate the length of time a cell was in metaphase. Show your working. (2 marks)

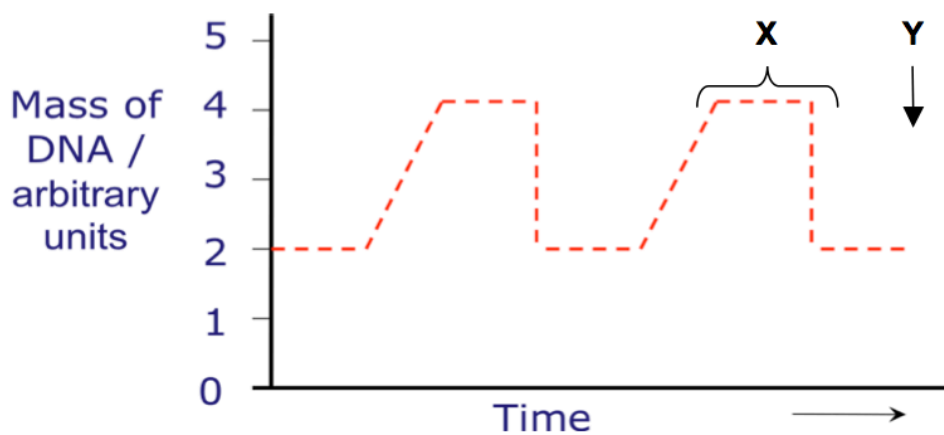
**5** Cisplatin is a substance that prevents DNA from replicating.

(a) The scientist put another root tip from the same plant in a solution of cisplatin and left it for 2 days. She then found the percentage of cells that were in each phase of the cell cycle.

How would you expect these figures to be different from those in the table? Explain your answer. (3 marks)

(b) Explain why cisplatin may be used to treat cancer. (2 marks)

The graph shows how the mass of DNA in an animal cell changed over two cell cycles.



**6** What phase of the cell cycle is represented by X? Explain the evidence for your answer. (3 marks)

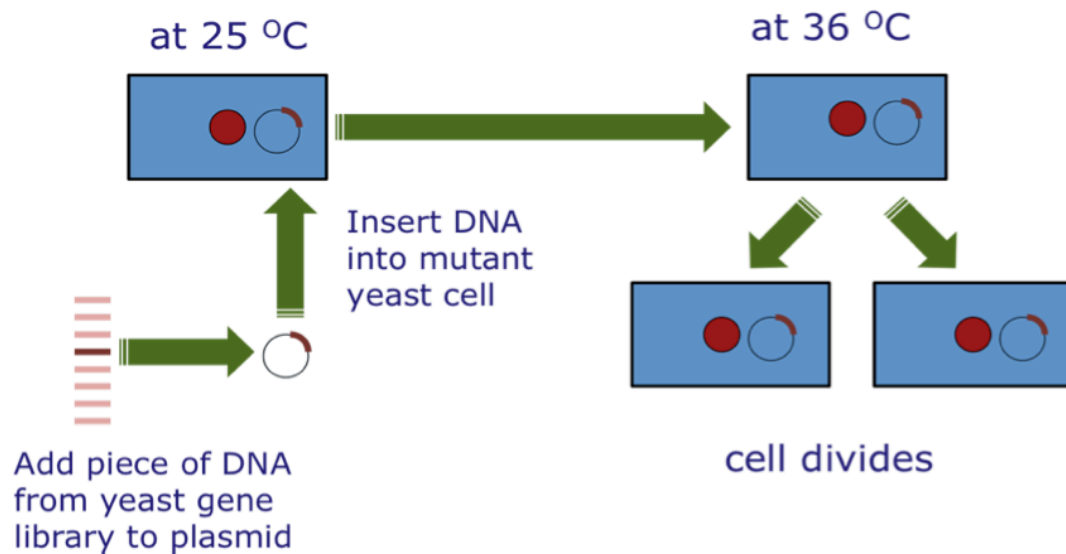
**7** Use your knowledge of what happens to chromosomes during mitosis to explain the change in mass of DNA at time Y. (3 marks)

**8** What mass of DNA would you expect to find in a sperm cell produced by this animal? Explain how you arrived at your answer. (3 marks)



The slide has been taken from the PowerPoint presentation on the cell cycle. In order to answer the questions you should read the article 'Controlling the cell cycle' in the September 2011 issue of BIOLOGICAL SCIENCES REVIEW.

### Identifying a mutant cdc gene



**9** The mutant cdc gene produces a non-functional protein at 36°C. Describe how a change in the base sequence of a gene can produce a non-functional protein. (2 marks)

**10** The yeast cell that contains the mutant cdc gene does not divide at a temperature of 36°C. Explain why it does not divide at this temperature. (1 mark)

**11** What do the results of this investigation suggest about the piece of DNA that has been added to the yeast cell? (1 mark)